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CALIBRATION OF A LOW COST CLOCK USING WIDE AREA AUGMENTATION SYSTEM (WAAS) (PREPRINT)

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THIS TECHNICAL REPORT IS APPROVED FOR PUBLICATION.

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14. ABSTRACT
The WAAS uses geo-stationary satellites to receive data measured from many ground stations and transmits information to GPS users for position correction. Since the WAAS satellites are geo-stationary, the Doppler frequency caused by their motion is very small, typically, in the order of a few tens of Hz. Thus, the signal transmitted by the WAAS can be used to calibrate the sampling frequency in a GPS receiver. The WAAS signal frequency is at 1575.42 MHz. The sampling frequency of a C/A code GPS receiver is in the neighborhood of 5 MHz. The ratio of these two frequencies is about 300, thus, 10 Hz inaccuracy in the WAAS frequency will be translated to about 0.03 Hz (10/300). The accuracy of the sampling frequency measured through this approach should be less than 1 Hz. The clock in a low cost Motorola GPS receiver (Model M12 Oncore) is used in this study. The WAAS signal can be rather weak for users in certain areas. Two seconds of data collected by a software receiver using the Motorola front end are used in this study. The result using this approach has been compared with an high accurate RF (Radio Frequency) frequency counter (1 Hz accuracy). There is no difference in result. The detail of the algorithms and the clock calibration is reported.

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Calibration of a Low Cost Clock using Wide Area Augmentation System (WAAS) Signals

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BIOGRAPHY

David M. Lin received the B.S.E.E. from Tatung Institute of Technology, Taiwan, 1970, the M.S.E.E. and the M.E.M.E. from Tennessee Technological University Cookeville, Tennessee, 1977, 1978 respectively and the M.S.C.S. from Wright State University, Dayton, Ohio, 1984. From 1979 to 1985, he was a software Engineer at System Research Laboratories, Inc. Dayton OH. Since 1985 he has been an Electronics Engineer at the Air Force Research Laboratory, Wright Patterson Air Force Base, OH. His work involves Electronic Warfare, radar and GPS receivers. He has received 10 patents

James B.Y. Tsui was born in Shantung, China. He received the B.S.E.E. degree from National Taiwan University, Taiwan, the M.S.E.E. degree from Marquette University, Milwaukee, WI, and the Ph.D. degree in electrical engineering from the University of Illinois at Urbana, in 1957, 1961 and 1965 respectively. From 1965 to 1973, he was an Assistant Professor and then Associate Professor in the Electrical Engineering Department of the University of Dayton, Dayton, OH. Since 1973 he has been an Electronics Engineer at the Air Force Research Laboratory, Wright Patterson Air Force Base, OH. His work is mainly involved with microwave receivers and his recent research is on digital microwave receivers and global positioning system (GPS) receivers. He has written four books on microwave and digital receivers, two chapters for two books and published over 70 technical papers. He has received about 30 patents

ABSTRACT

The WAAS uses geo-stationary satellites to receive data measured from many ground stations and transmits information to GPS users for position correction. Since the WAAS satellites are geo-stationary, the Doppler frequency caused by their motion is very small, typically, in the order of a few tens of Hz. Thus, the signal transmitted by the WAAS can be used to calibrate the sampling frequency in a GPS receiver. The WAAS signal frequency is at 1575.42 MHz. The sampling frequency of a C/A code GPS receiver is in the neighborhood of 5 MHz. The ratio of these two frequencies is about 300, thus, 10 Hz inaccuracy in the WAAS frequency will be translated to about 0.03 Hz (10/300). The accuracy of the sampling frequency measured through this approach should be less than 1 Hz. The clock in a low cost Motorola GPS receiver (Model M12 Oncore) is used in this study. The WAAS signal can be rather weak for users in certain areas. Two seconds of data collected by a software receiver using the Motorola front end are used in this study. The result using this approach has been compared with an high accurate RF(Radio Frequency) frequency counter(1 Hz accuracy). There is no difference in result. The detail of the algorithms and the clock calibration is reported.

INTRODUCTION

The pseudo-range calculated for a GPS receiver depends on the accuracy of the sampling frequency. If the sampling frequency is inaccurate, the pseudo-range will have error, which reflects on the calculated user position. An accurate oscillator is rather expensive. The accuracy of a low cost oscillator is usually poor and the output frequency can be off from the specified value. It is important to measure the true sampling frequency of a receiver. One way is to use a frequency counter in the laboratory to measure the sampling frequency. However, this instrument may not be available to some users.

The WAAS uses geo-stationary satellites to receive data measured from many ground stations and transmits information to GPS users for position correction. Since the WAAS satellites are geo-stationary, the Doppler frequency caused by their motion is very small, typically, in the order of a few tens of Hz. Thus, the signal transmitted by the WAAS can be used to calibrate the sampling frequency in a GPS receiver. The WAAS signal frequency is at 1575.42 MHz. The sampling frequency of a C/A code GPS receiver is in the neighborhood of 5 MHz. The ratio of these two frequencies is about 300, thus, 10 Hz inaccuracy in the WAAS frequency will be translated to about 0.03 Hz (10/300). The accuracy of the sampling frequency measured through this approach should be less than 1 Hz. However, the WAAS signal can be rather weak for users in certain areas. The noise in the received signal can be the dominant factor in determining the sampling frequency.

WASS SATELLITE SIGNAL

The C/A codes of the WAAS satellites can be generated through a code generator using the code delay chips in Table 1. [1]:

Table 1 WASS Satellites Code Delay Chips

PRN	Code delay chips	First 10 chips C/A Octal
120	145	0671
121	175	0536
122	52	1510
123	21	1545
124	237	0160
125	235	0701
126	886	0013
127	657	1060
128	634	0245
129	762	0527
130	355	1436
131	1012	1226
132	176	1257
133	603	0046
134	130	1071
135	359	0561
136	595	1037
137	68	0770
138	386	1327

The C/A code in the WAAS is also periodic with 1 ms code length, however, the navigation data rate is 500 Hz, which is 10 times higher than the satellites in the GPS constellation. Because of this high data rate, long coherent integration will encounter many data transitions. Therefore, it is decided to perform 1-ms coherent integration and 20-ms incoherent integration for acquisition.

DATA COLLECTION HARDWARE

The data collection system used in this paper is a modified Motorola GPS receiver (Model M12 Oncore) front end. The frequency plan of data collection system is shown in Figure 1.

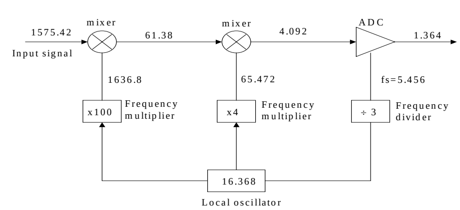

Figure 1. Frequency plan of a Motorola GPS receiver front end

In this figure the numbers are frequencies in MHz, which can be considered as nominal values because they are provided by the manufacture but are not accurate. The purpose of this paper is to find the accurate sampling frequency (f_s.) The nominal frequency for this receiver in the specification is f_s = 5.456 MHz.

TIME DOMAIN SAMPLING CLOCK CALIBRATION TECHNIQUE

The measurement is based on time domain analysis. The length of the C/A code transmitted is 1 ms. However, Doppler frequency can change this value. Since the signal from the WAAS satellite has near zero Doppler frequency, the time of each C/A code should be very close to 1 ms. For this operation it is assumed that Doppler frequency is zero and the received C/A code length is 1 ms. If the sampling frequency is correct, every C/A code will have 5456 points of digitized data. With the correct sampling, the initial C/A code phase will remain the same whether acquisition is performed on the 1st ms or the 1001th ms. If the assumed frequency is incorrect, the initial C/A code phase will change. This phenomenon can be explained in Figure 1.

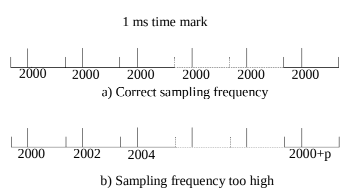

Figure 1 Shift of initial phase of C/A code

In Figure 1a the sampling frequency is at the correct value. The initial C/A code phase is a constant value from one ms to another. In Figure 1b the sampling frequency is higher than the nominal value, thus, in one ms there are more than 5456 sampled data points. The initial C/A code phase is keeping increase from one ms to another. In this example the initial C/A code measured will move toward right. Based on the time difference the true sampling frequency can be found.

Theoretically, this measurement is very simple and only two points are needed. For example, one can obtain the initial C/A codes at 1st and 1001st ms through acquisition. If the initial point has shifted to the right, the sampling frequency is higher than the nominal value. Assume that the initial C/A code measured in the 1st ms is at 2000 and the initial C/A code measured at the 1001st ms shifted by p points, the result should be 2000+p. Since from 1st to 1001st ms covers on 1 second of time, there are total 5456000+p samples. Thus, the actual sampling time t_s is

$$t_s = \frac{1}{5456000 + p} \quad or$$

$$f_s = 5456000 + p \; Hz \tag{1}$$

This simple equation can be used to find the sampling frequency. Since the noise can cause error in the measurement, this simple method maybe inadequate.

In actual determining the sampling frequency the process is discussed as follows. Using one ms of data to perform coherent integration and 20 ms for incoherent integration, the initial point of the C/A code is determined every 20 ms. In 2 seconds this 20 ms operation is performed 100 times. The length of the data used is not very critical but should depend on the signal strength. For strong signal, less data can be used. This idea is to use 100 points of 20 ms data averaged to obtain a more dependable result. A typical initial C/A code measured over 2 seconds of time is shown in Figure 2, which contains 100 data points.

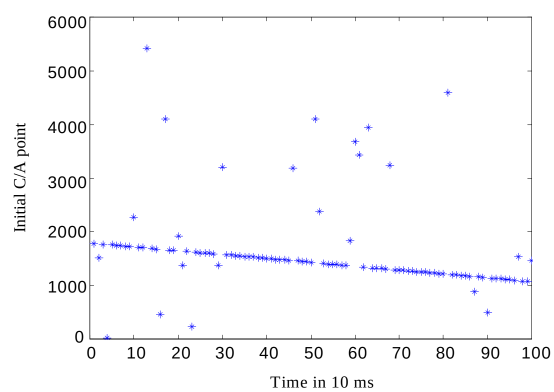

Figure 2 Initial phase of C/A code versus time

Each data point is obtained from 20 ms of data. One can see that most of the data are somewhat fit on a straight line and let us refer to this line as the "desired line" but there are many obviously

erroneous points. In determining the initial C/A code sometimes the values wrap around. For example, if in the 1st 20 ms the initial C/A code measured is 4 and the second 20 ms the value is 5454, the first value can be adjusted by adding 5456. In this example, the first value will become 5460 (4+5456). In general, if there is a wrap around, either the value before the wrap around or the values after it must be adjusted by 5456.

The following operation is used to eliminate the erroneous points and to find the slope of the desired line. There might be many ways to accomplish this goal. One of the methods is presented here. Figure 3 shows

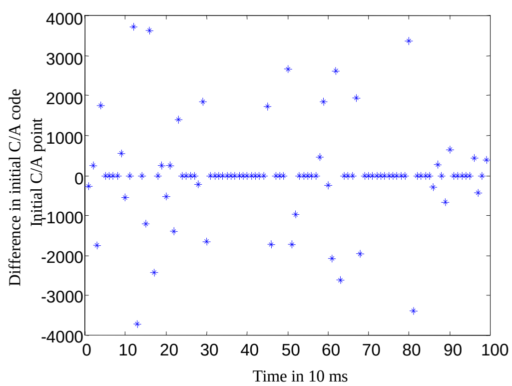

Figure 3 Difference of initial phase of C/A code versus time

the difference values between two adjacent initial C/A codes. The majority differences are close to a constant value and it is desirable to keep them. Figure 4 shows the sorted difference values in ascending order.

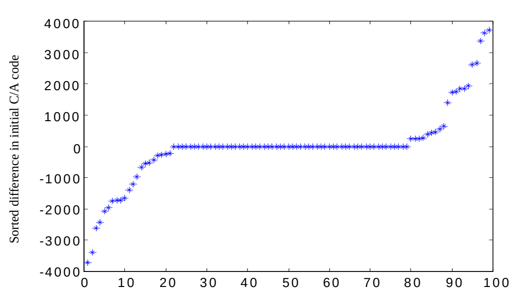

Figure 4 Sorted difference of initial phase of C/A code

The horizontal axis simply represents the index associate with the difference ranking order. The sorted results in the center portion are the desired ones, which are shown in Figure 5. This figure can be considered as the magnifying version of Figure 4.

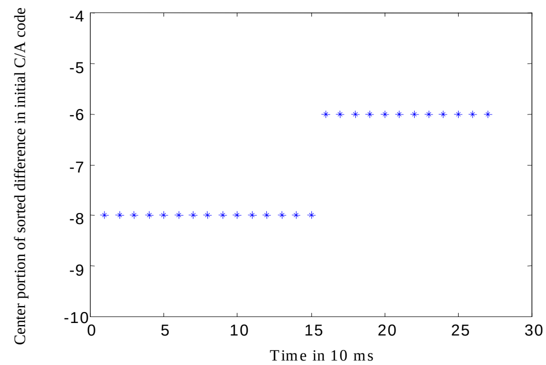

Figure 5 Center portions of the sorted results

Since in the acquisition for the coherent integration, the data is shifted 2 samples, the time resolution for the initial C/A code can be considered as 2 sampling points. As a result, the measured initial C/A code change is either -6 samples or -8 samples every 20 ms because the resolution is 2 samples. That is why the differences of initial C/A codes are divided into two groups: -8 and –6 in Figure 5. Arbitrarily using 25 points of the center portions of Figure 5 to avoid the erroneous difference values on the ends, an average value and a standard deviation can be found from these 25 points. The average value is close to the slope of the desired line. The standard deviation can be used as limit to eliminate erroneous data points. One can draw a straight line passing through a "valid" initial C/A code data phase by using the average value as the slope. A valid initial C/A point is a point on the desired line in Figure 2. It can be determined from the difference initial points. If a difference initial C/A code value obtained from two adjacent points n_k and n_{k+1} is very close to the average value, both n_k and n_{k+1} are valid points. Select ±50 times of standard deviations as the threshold to eliminate the erroneous points. The value 50 is obtained from experimenting with the values shown in Figure 2. Figure 6 shows that the two lines to limit the "good" points.

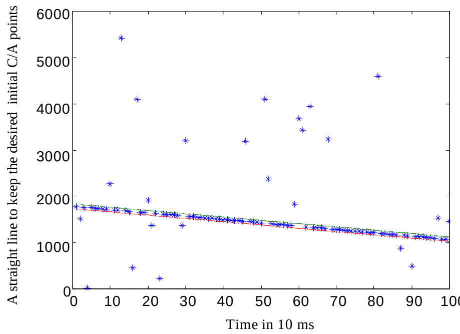

Figure 6 Border lines to separate "good" and "bad" data

Finally, these good points are fitted into a straight line as shown in Figure 7. From this line, one can find two

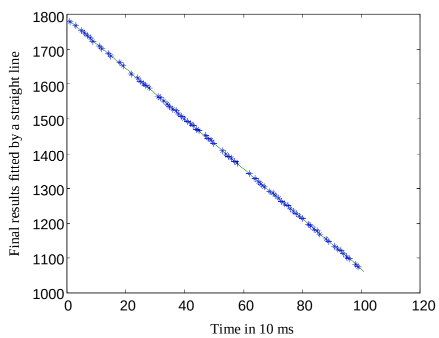

Figure 7 A line is extrapolated from "good" data

points: the initial C/A codes correspond to x(1) and x(101) and call them y(1) and y(101).
In this example, although there are only 100 raw data points obtained from the measurement, any values on the line can be used to find the total initial C/A code phase change. From x(1) to x(101) cover 2 second of time. The number of points shifted per second can be calculated as

$$p = \frac{y(1) - y(101)}{2} \qquad (2)$$

Once the value of p is found, the sampling frequency can be found from Equation (1).

Every 2 seconds of data are used to calculate the sampling frequency. The sampling frequency is calculated 54 times, which means the length of the data is 110 seconds.

CONCLUSION

This approach was used to determine the sampling frequencies of two Motorola front ends. The average sampling frequencies measured are 5455656.85 and 5455640.80 Hz with standard deviations of 0.22 and 0.26 Hz respectively. A frequency counter was used to measure the front end with 5455640.80 Hz sampling frequency and the reading is between 5455641 and 5455642 Hz because the counter has a resolution of 1 Hz. A very stable signal generator was used to generate a signal at 5455640.80 Hz, the signal is measured by the frequency counter, which also displayed 5455641 and 5455642 Hz. This experiment indicates that the measurements are rather accurate, almost as close as the frequency counter. The algorithm used here is just for demonstration of the concept and by no mean is optimal. There should be more efficient algorithms can be developed for this purpose.

Reference

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